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NOLTR 61-43

A LIGHTNING STRIKE OF AN UNDERWATER EXPLOSION PLUME

1 FEBRUARY 1962

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

655 000

NOLTR 61-43

A LIGHTNING STRIKE OF AN UNDERWATER EXPLOSION PLUME

by

George A. Young

Approved by: E. Swift, Jr., Chief
Underwater Explosions Division

ABSTRACT: An unexpected lightning strike to an underwater explosion plume is described. Four pulses occurred, lasting a total of one second. Photographic evidence indicates that the discharge probably started upward from the plume. The occurrence provides support for the viewpoint that the rapid introduction of a conductor into the electric field of a storm would be a useful experimental technique for triggering a lightning stroke.

PUBLISHED MARCH 1962

EXPLOSIONS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

A LIGHTNING STRIKE OF AN UNDERWATER EXPLOSION PLUME

This report describes the unexpected lightning strike of a plume of water during an underwater explosion test series conducted by the Naval Ordnance Laboratory. The explosion work is part of a continuing program currently under WEPTASK No. RE01-ZA732/212 9/WF008-21-003, which is titled Delivery Criteria for Underwater Nuclear Weapons. As the objectives of this Task are of a totally different nature, no further study of lightning is contemplated. However, the available information is summarized here for the use of scientific workers, in particular those engaged in the fields of meteorology and lightning protection.

The author is pleased to acknowledge the helpful comments and suggestions made by Mr. Charles B. Moore of Arthur D. Little, Inc. and Mr. J. H. Hagenguth of the General Electric Company. Their expert opinions provided valuable guidance during the preparation of this report.

W. D. COLEMAN
Captain, USN
Commander

C. J. Aronson

C. J. ARONSON
By direction

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A LIGHTNING STRIKE OF AN UNDERWATER EXPLOSION PLUME

1. INTRODUCTION

During June 1957, the Underwater Explosions Division of the Naval Ordnance Laboratory was engaged in a program whose purpose was to measure the phenomena occurring when conventional mines and depth charges are exploded under water at various depths. The series was conducted in Chesapeake Bay in a restricted area often used by the Navy for explosive firings.

On 14 June, lightning struck the plume from the eighth explosion in the series. As this type of occurrence is extremely rare, it aroused considerable public interest and attracted the attention of scientific workers in the fields of meteorology and lightning protection. This report summarizes the existing information on the lightning strike and presents a discussion of the possible causes and implications.

2. DESCRIPTION OF PHENOMENA

The mine employed in Test No. 8 was placed in the water about 1235 EST on 14 June 1957, when the sky was clear. However, difficulty was encountered with the electronic recording equipment and it was not possible to detonate the charge until 1351 EST. At that time, the sky was more than half covered with clouds and a thunderstorm was approaching from a southerly direction.

The weather observations at the firing site did not include a detailed description of the cloud cover. However, the records show the following: air temperature 77°F, dew point 74°F, relative humidity 91%, water temperature 72°F, wind direction 170 degrees, and wind speed 10 to 12 knots.

Table I is a transcript of the weather observations at the Patuxent River Naval Air Station during the period of interest. This station is located about six nautical miles southwest of the firing site in the bay. The thunderstorm reported by the Naval Air Station to be moving northeast at 1330 EST was most probably the storm observed to be approaching the firing site at the time of the explosion.

When the explosion occurred, water was ejected into the air in the form of plumes (Reference 1). A broad central vertical plume was the first to appear, followed by several radial plumes which seemed to originate at its base. The central plume was struck by lightning at 1.61 seconds after the explosion, when the plume was 244 feet high.

TABLE I

SURFACE WEATHER OBSERVATIONS

U. S. NAVAL AIR STATION, PATUXENT RIVER, MARYLAND - 14 June 1957

Time (EST)	Sky and Ceiling (ft)	Visi-bility (miles)	Weather and Obstructions to Vision	Sea Level Press. (millibars)	Temp. (°F)	Dew Point (°F)	Relative Humidity (%)
1100	Clear	6	Haze	1013.9	82	74	77
1200	Clear	7		1013.9	84	75	75
1300	*E3000 Broken	7		1013.6	86	74	68
1330	*E3000 Broken	7	Thunder				
1400	*E3000 Broken	7	Thunderstorm Light Rain Shower	1013.7	81	74	80
1413	2000 Scattered *E3000 Broken	7	Thunderstorm Light Rain Shower		81	74	80
1500	2000 Scattered *E3000 Broken	7	Thunderstorm Light Rain Shower	1014.3	73	67	81
1600	3000 Scattered *E6000 Broken	7		1014.0	74	70	86

Time (EST)	Wind Direction	Wind Speed (Knots)	Remarks
1100	SE	10	Few cirrocumulus
1200	SE	17	Few altocumulus, haze all quadrants
1300	SE	15	
1330	SE	13	Thunderstorm overhead moving NE, began 1330 EST
1400	SW	10	Thunderstorm overhead moving N, began 1330 EST lightning cloud-to-cloud overhead, rain began 1338 EST
1413	W	16	
1500	WSW	10	
1600	S	8	Rain ended 1540 EST peak gusts 25 knots

*Estimated

The complete event was recorded by motion picture cameras on the deck of the EPCS-1413, an experimental ship located 1050 feet from the explosion. The camera data are summarized in Table II.

TABLE II

CAMERA DATA

Camera No.	Camera Type	Lens Focal Length	Film	Filters	Frame Rate
No. 1	Mitchell	25.8 mm	35 mm Plus X	none	23.8 fps
No. 2	Mitchell	49.6 mm	35 mm Plus X	none	109 fps
No. 3	Cine Special	15 mm	16 mm Kodachrome	none	*64 fps

*Nominal

The frames from Cameras 1 and 2 which show the lightning strike are reproduced in entirety in Figures 1 and 2. Times are indicated to the nearest 0.01 second. Camera 1 had a wider field of view and shows more of the lightning; however, Camera 2, which had a higher frame rate, provides a better resolution of the time scale of the phenomena.

Four lightning discharges are detectable on the 109 frame per second record from Camera No. 2. They lasted about 0.62, 0.16, 0.05, and 0.17 seconds for a total of 1.00 second. The starting frame for each stroke is marked with an arrow in Figure 2. All strokes followed the same path, and each secondary discharge appeared before the preceding one had completely disappeared. An interesting result was the appearance of beads as each discharge faded. The width of the path, as measured on Film No. 2, was apparently about 2 feet. However, because of such factors as overexposure, inadequate optical resolution, film grain structure, and the twisting path of a lightning stroke, the image width in a photograph of lightning seldom indicates the correct diameter of the stroke channel (Reference 2). The true width of the stroke to the plume was doubtless less than 2 feet. Investigators of lightning generally agree on channel widths of the order of a few inches (Reference 3).

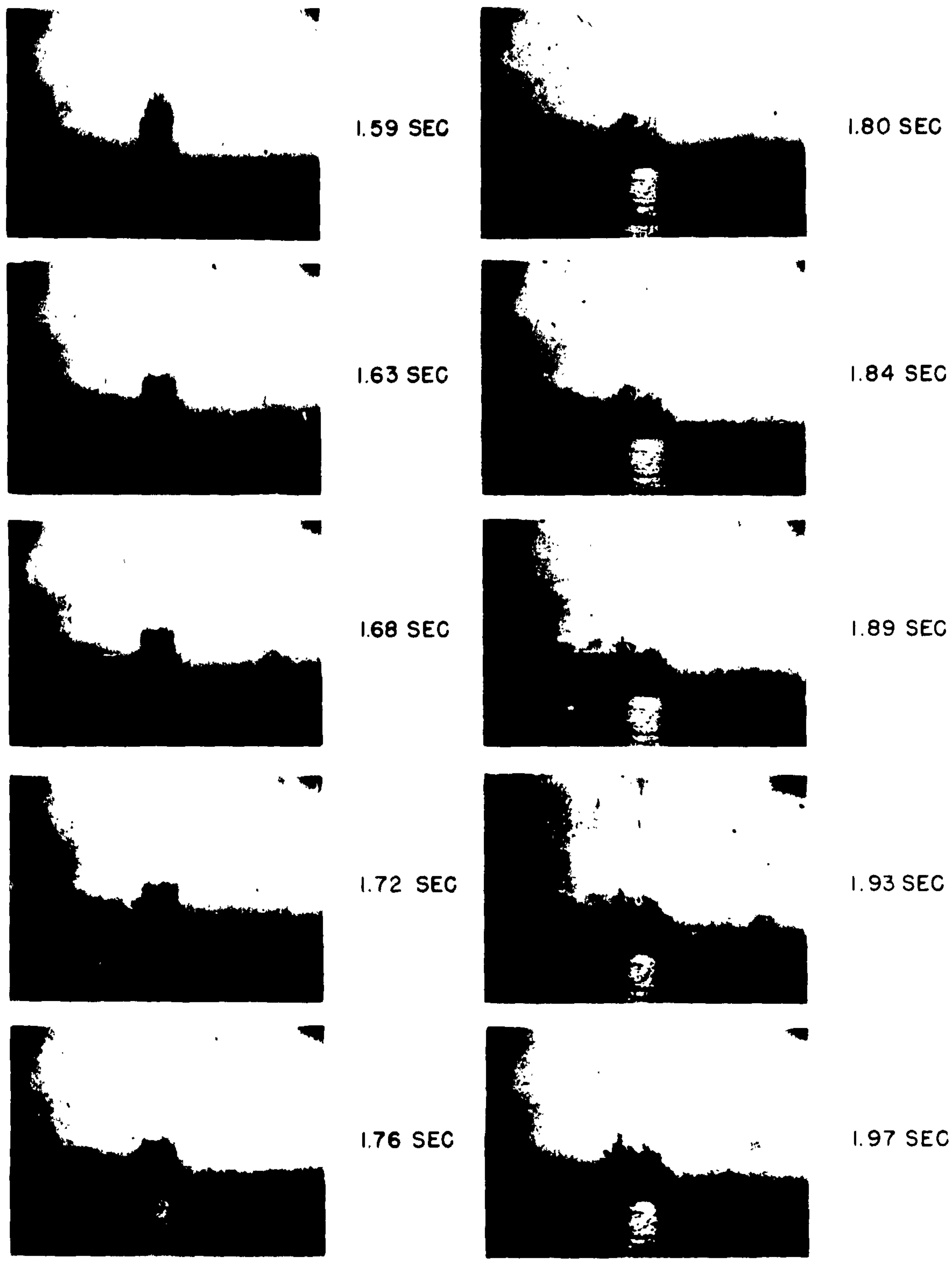


FIG. 1A FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA I

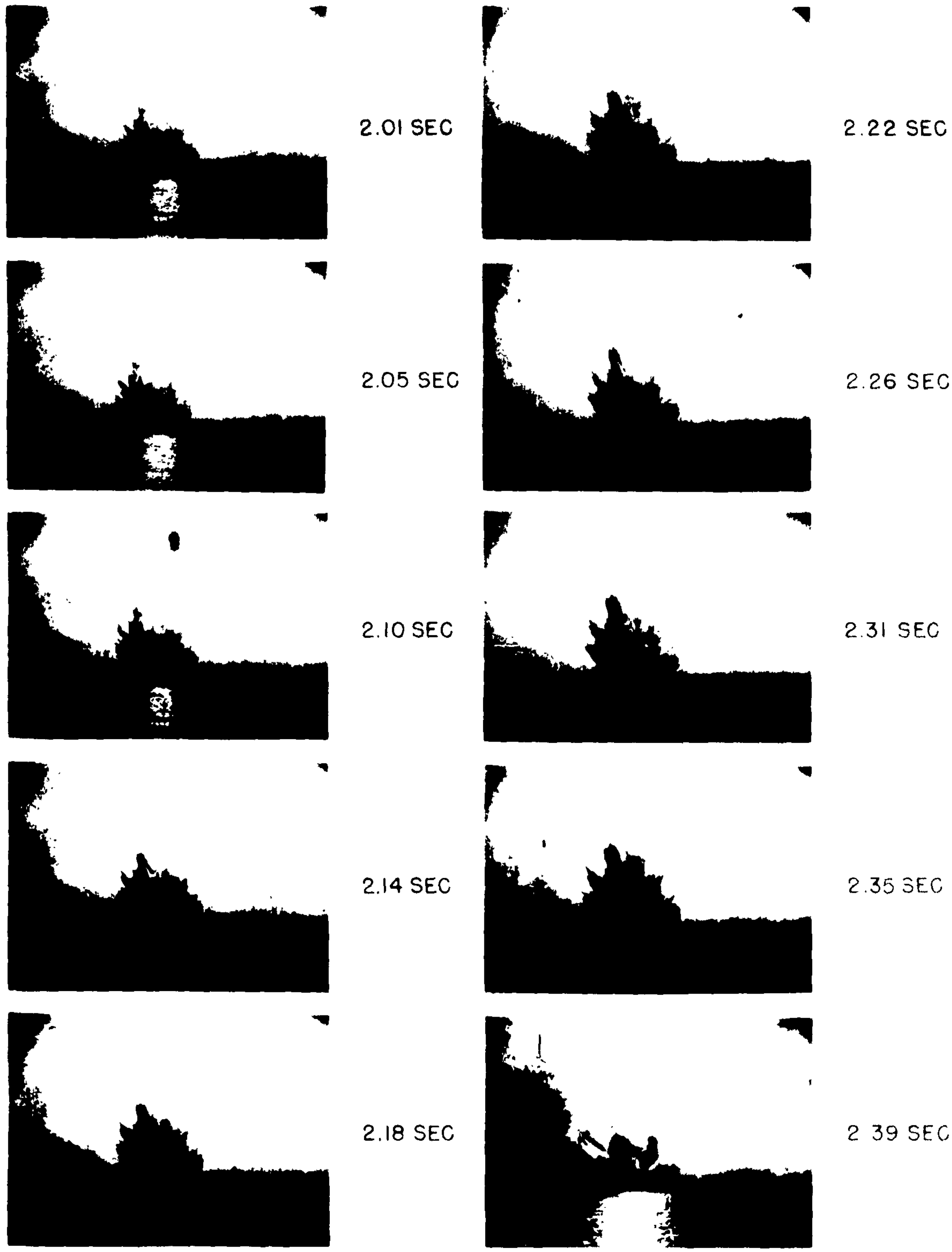
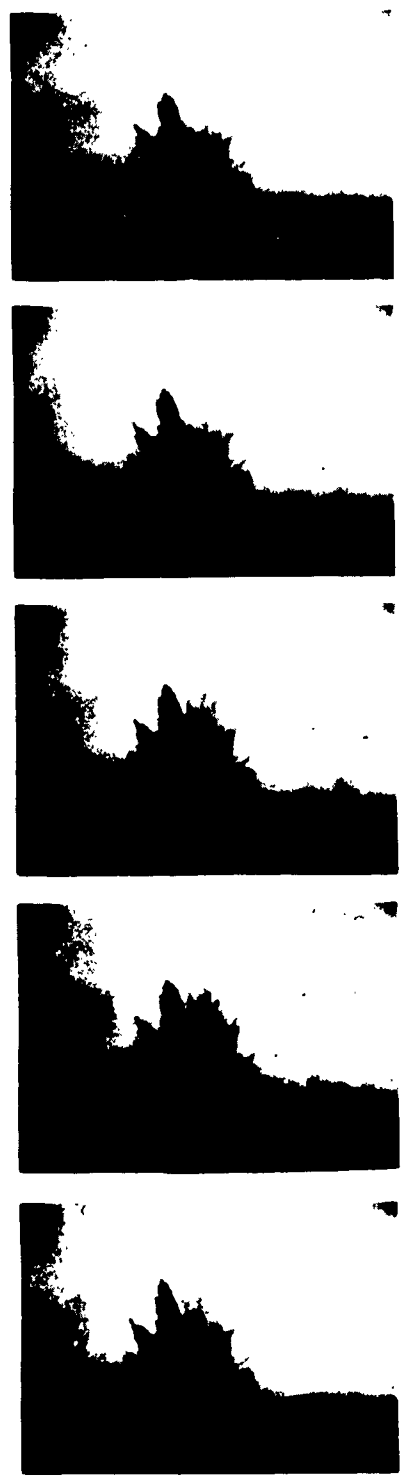


FIG. 1B FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 1



2.43 SEC

2.47 SEC

2.52 SEC

2.56 SEC

2.60 SEC

FIG. 1C FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 1

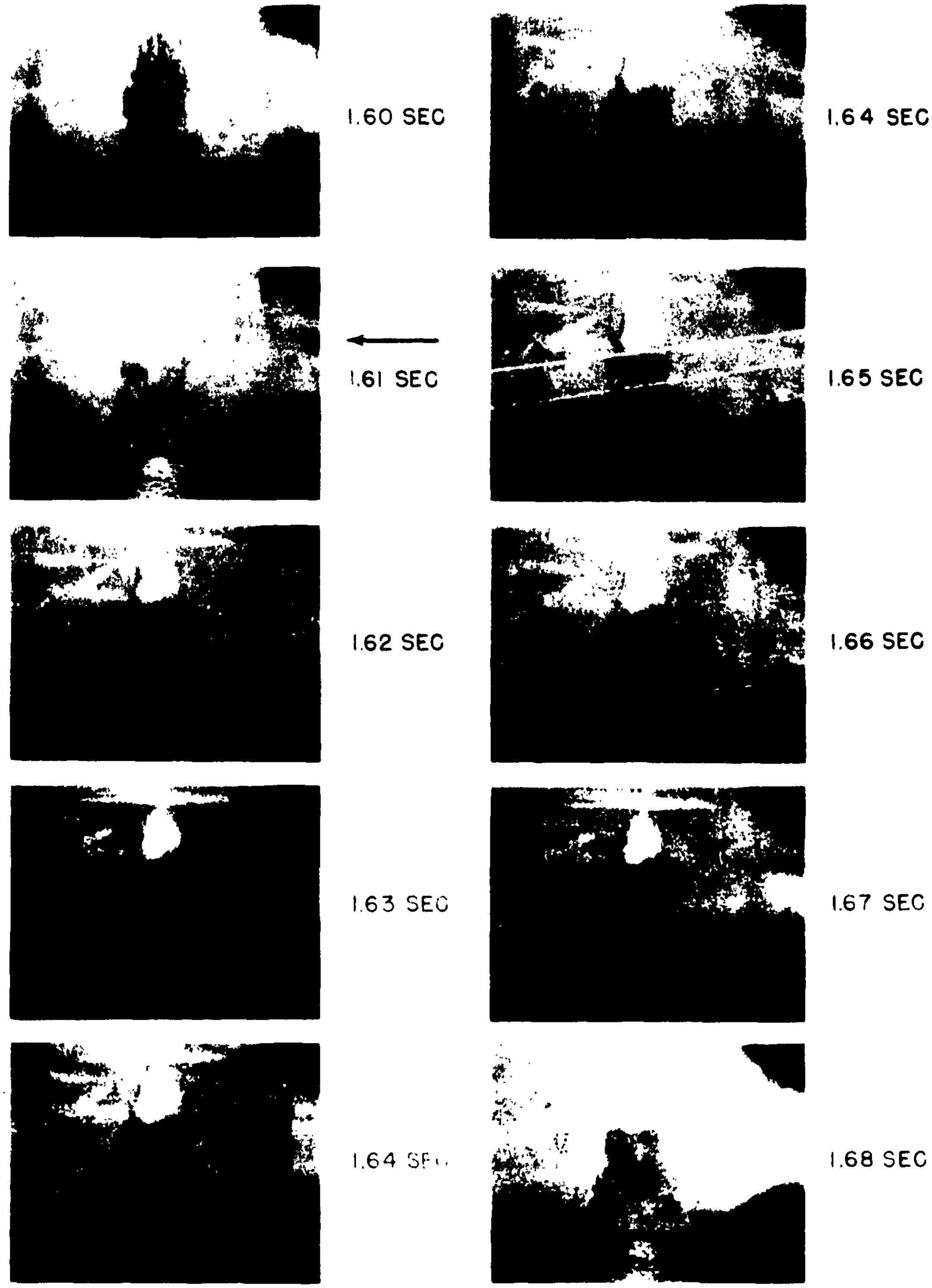


FIG. 2A FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 2

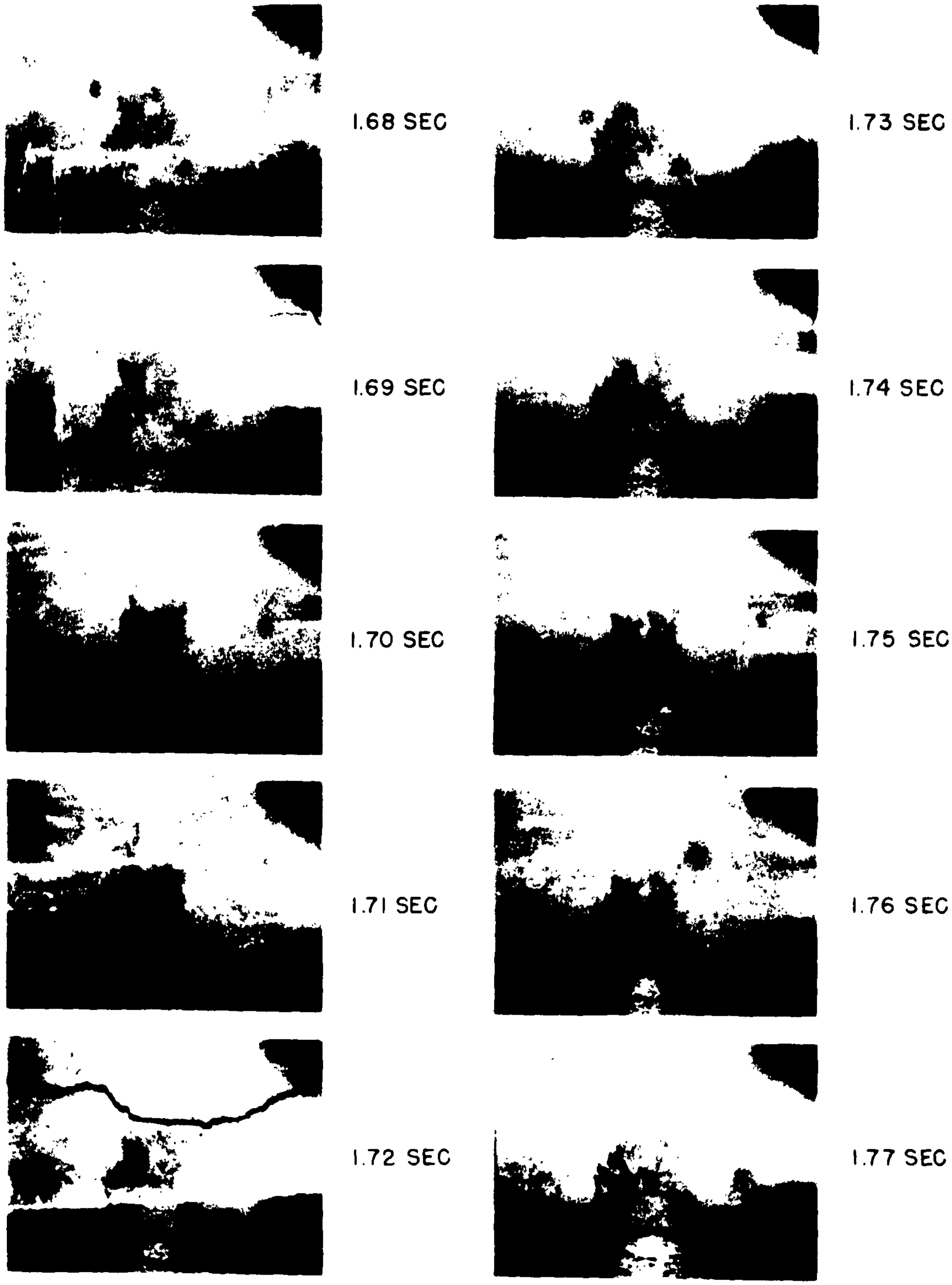


FIG. 2B FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 2

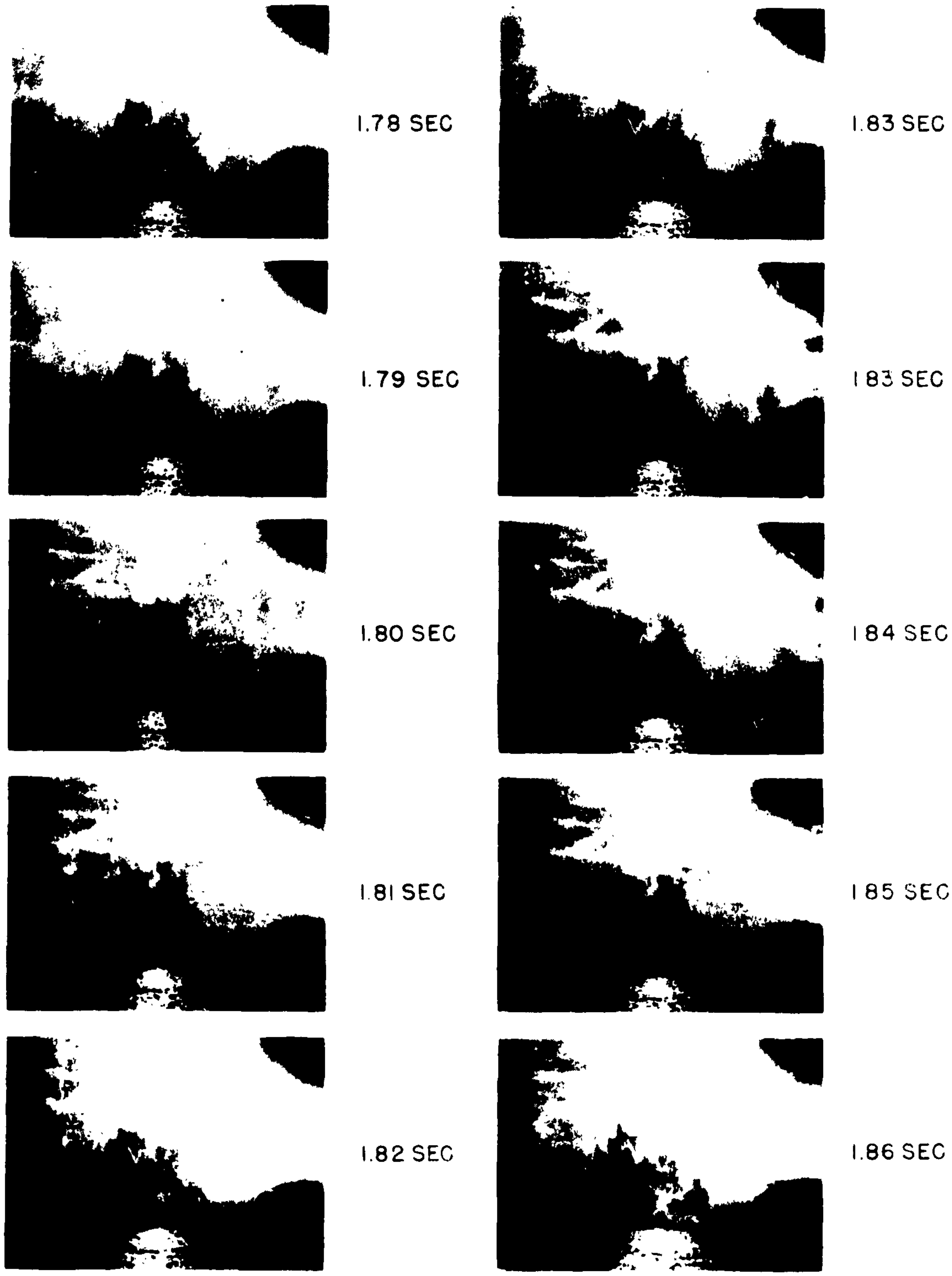


FIG. 2C FILM SEQUENCE OF LIGHTNING STRIKE–CAMERA 2

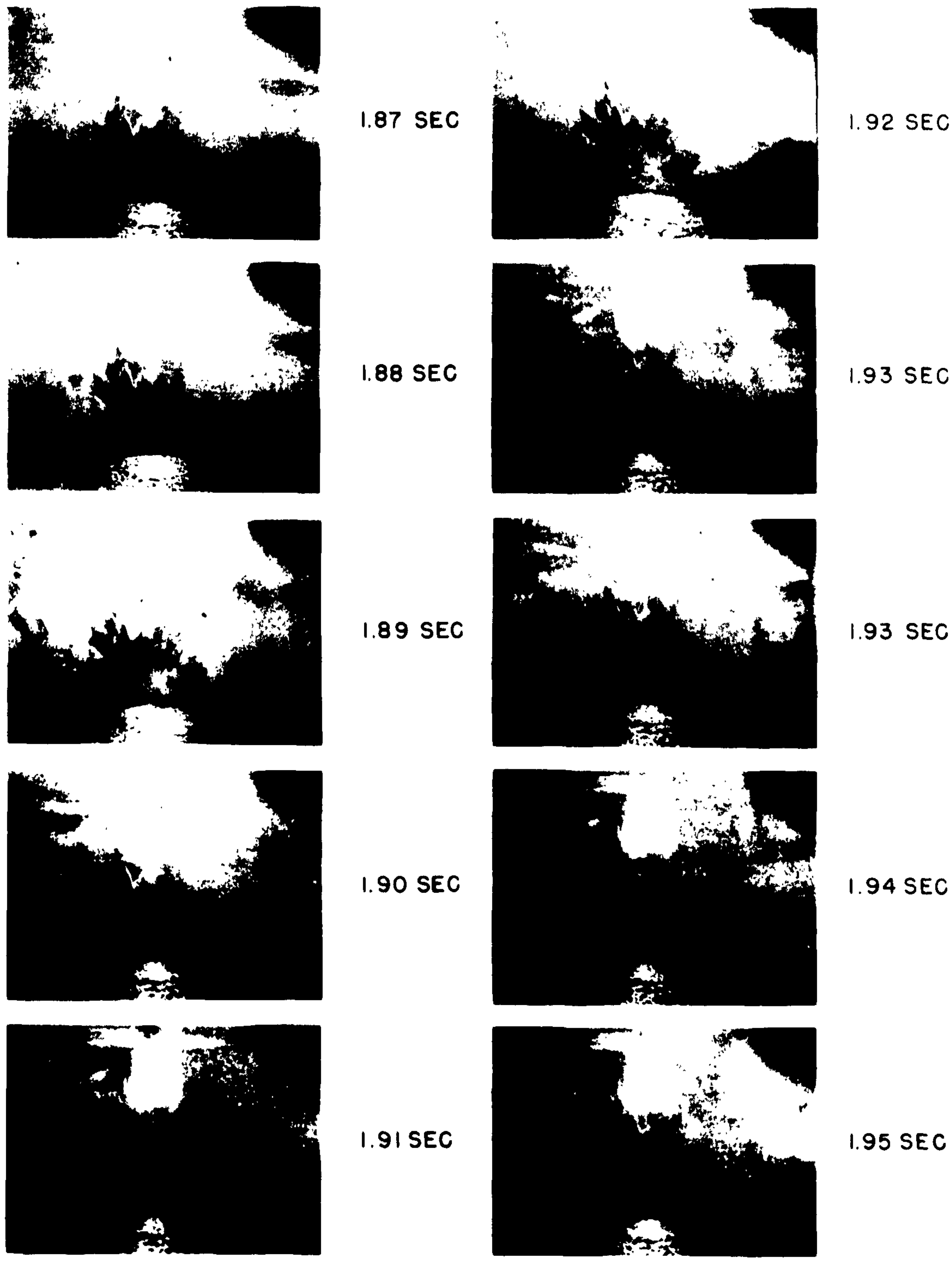


FIG. 2D FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 2

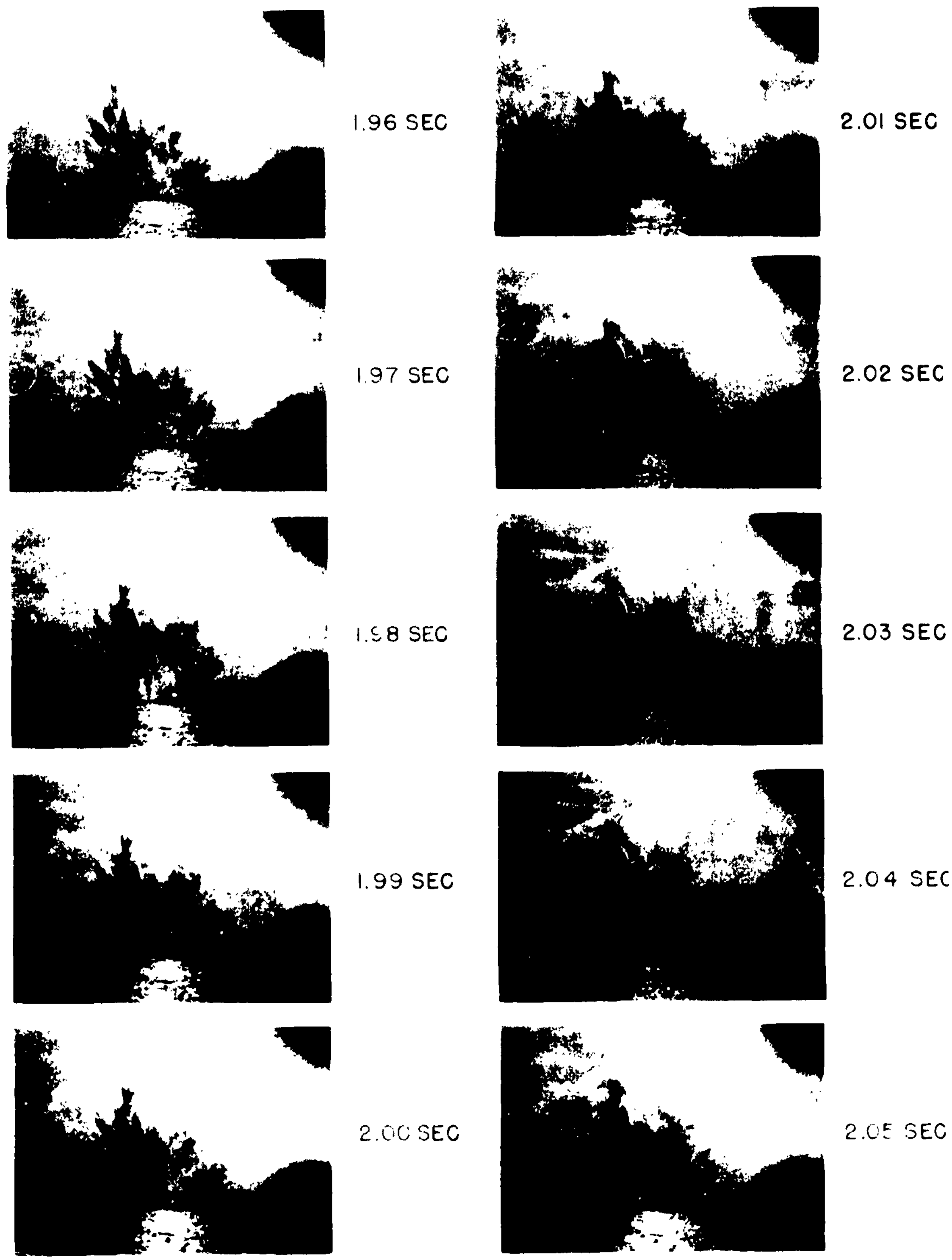


FIG. 2E FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 2

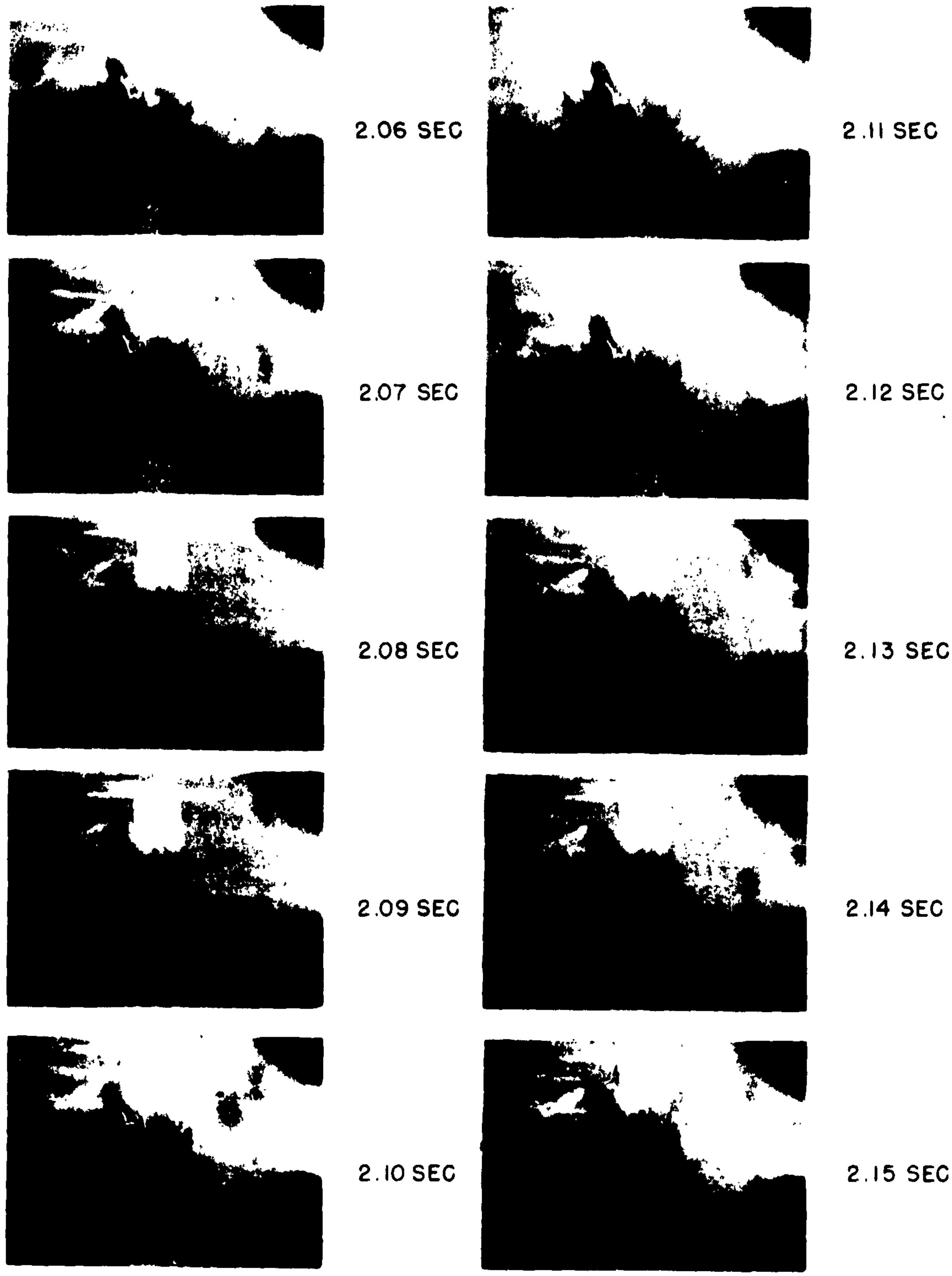


FIG. 2F FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 2

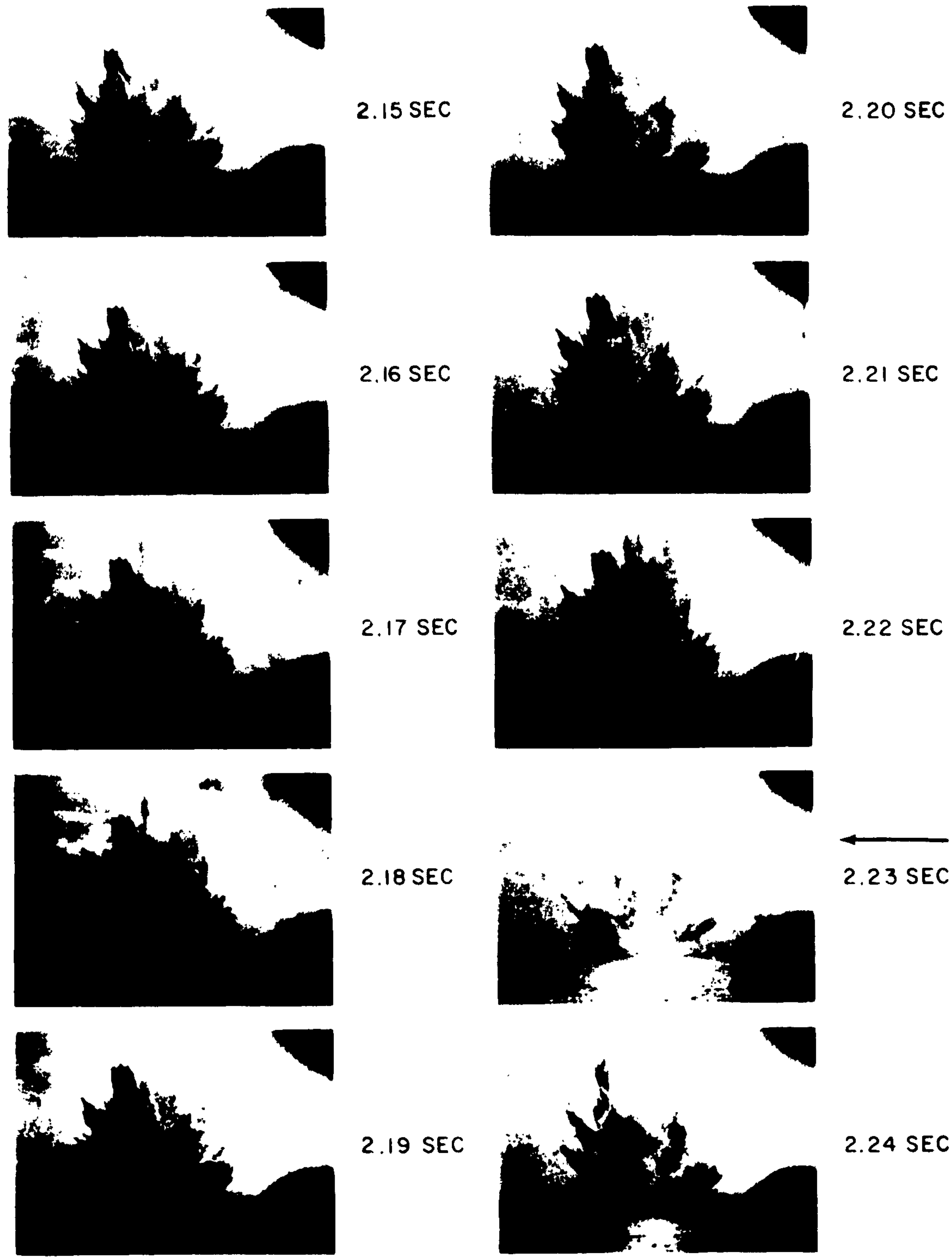


FIG. 2G FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 2

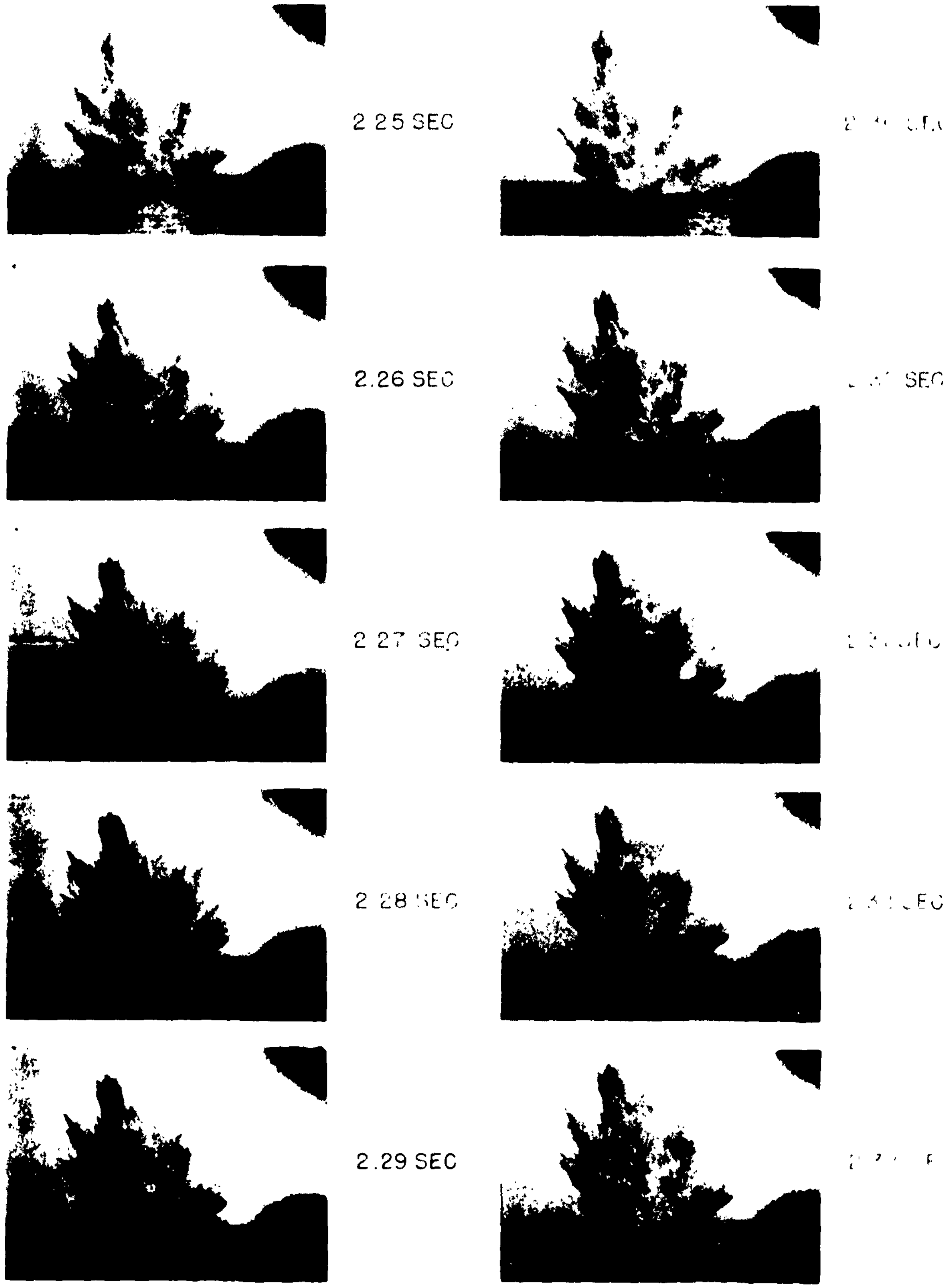


FIG. 2H FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA .

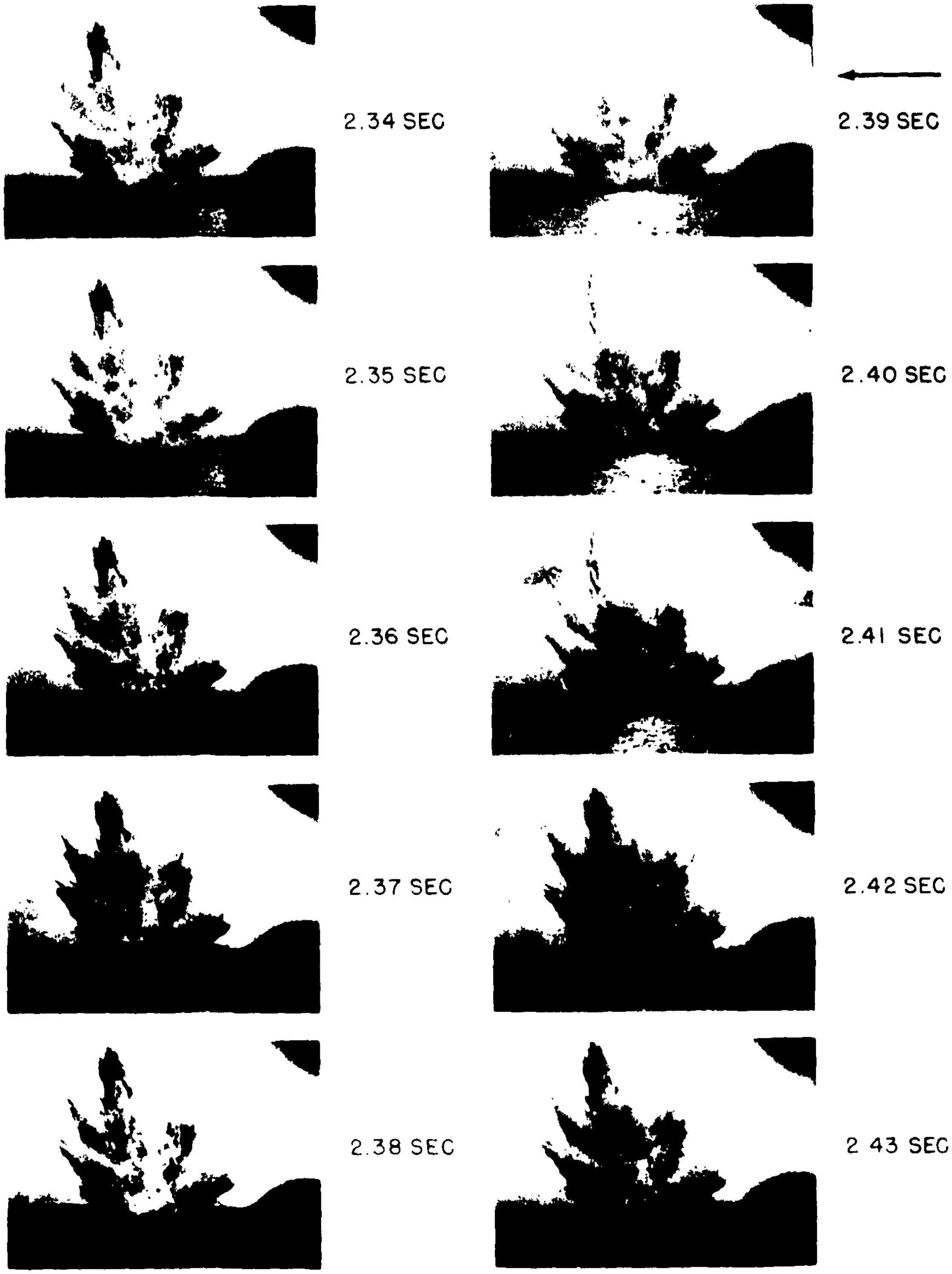


FIG 2I FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 2

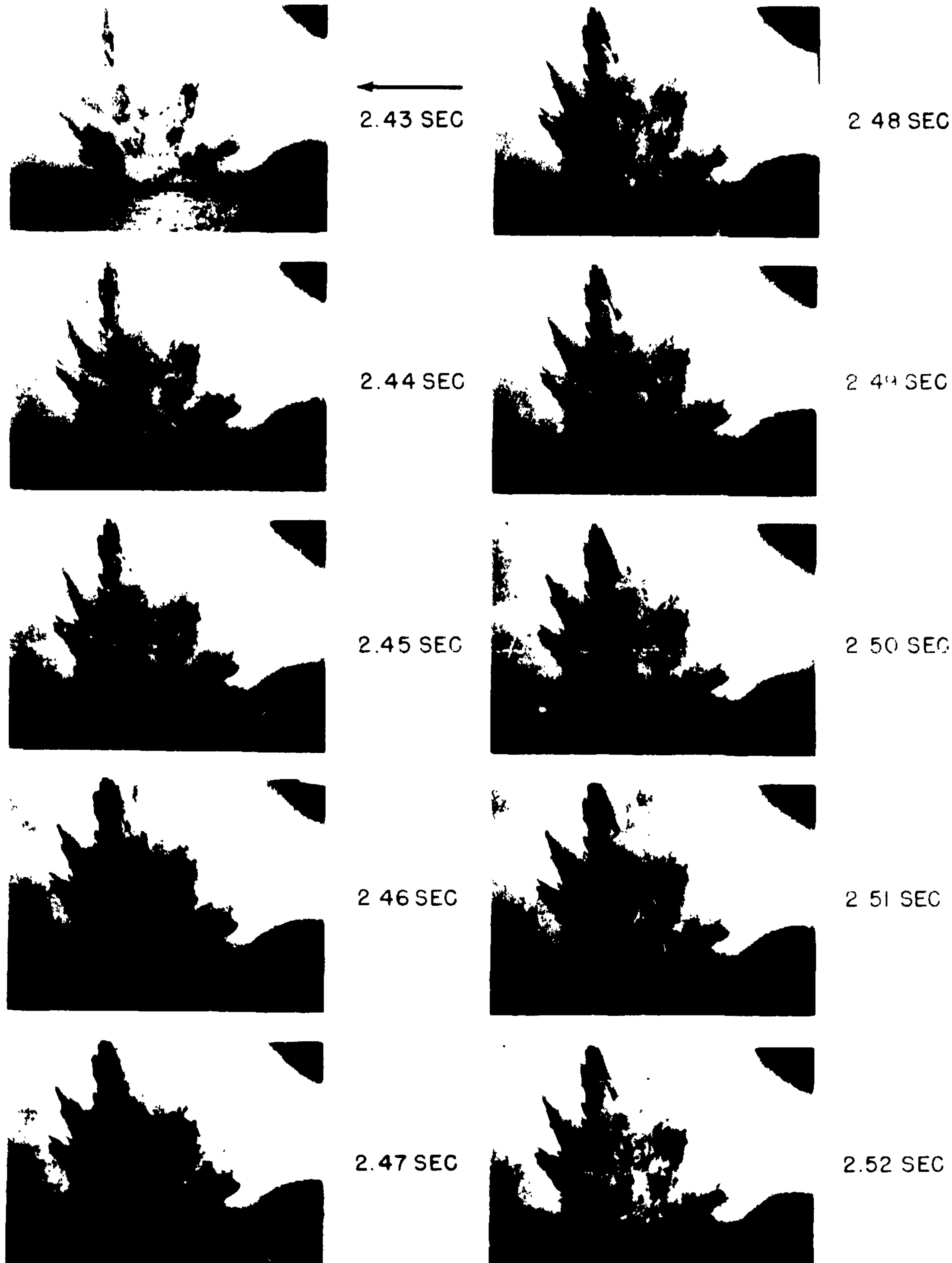


FIG. 2J FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 2

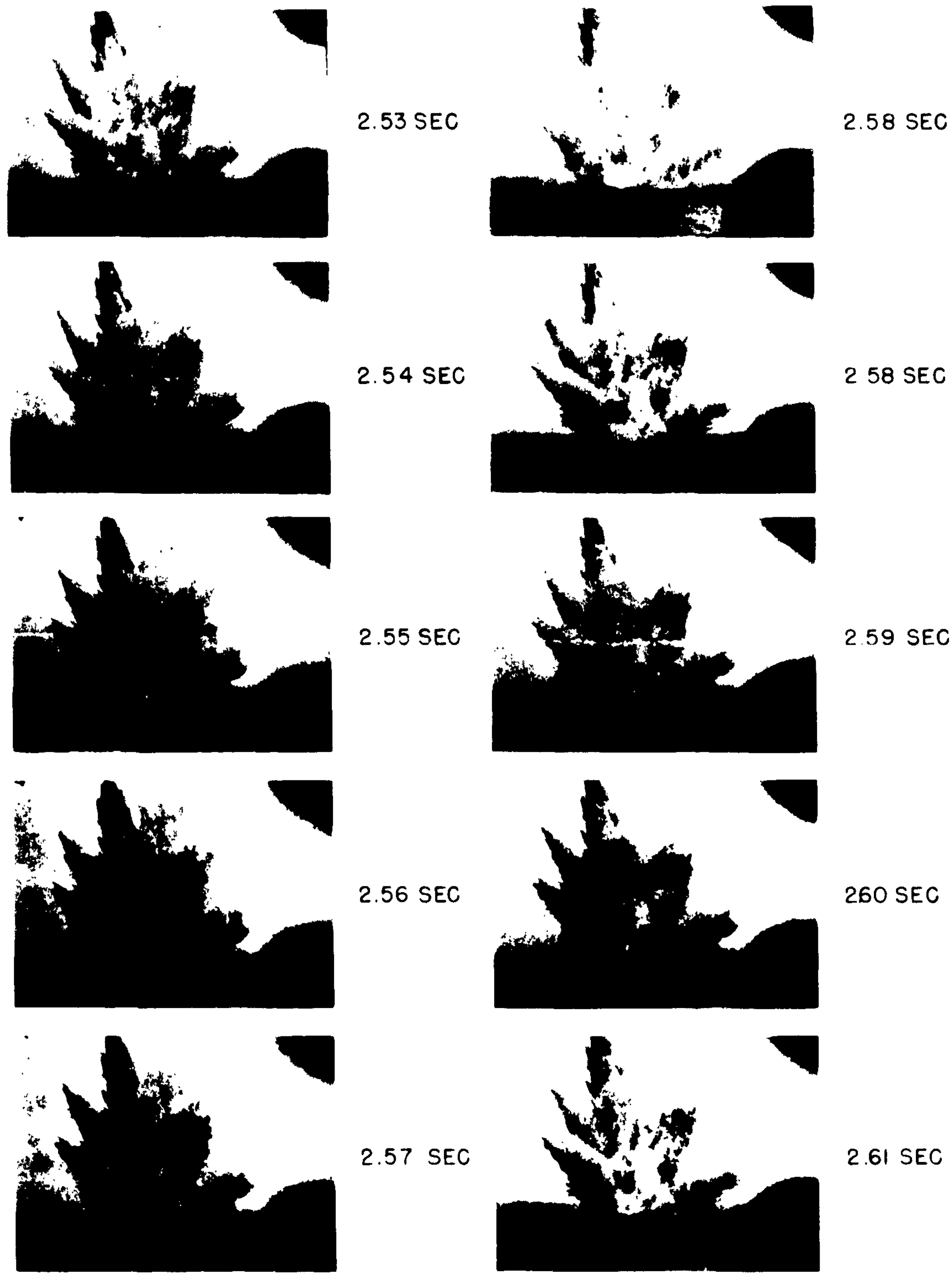


FIG. 2K FILM SEQUENCE OF LIGHTNING STRIKE-CAMERA 2

The height vs time curve for the central plume, for the first 2.5 seconds of its growth, is shown in Figure 3. The vertical velocity of the plume at the time of the strike was about 94 feet per second.

3. DISCUSSION

Photographs of the lightning strike of the explosion plume were released to the press on 14 October 1957. In addition to statements in newspapers and magazines, brief descriptions were included in References 4 and 5.

One reason this type of phenomenon is uncommon is that explosives are not usually handled in the presence of thunderstorms. In the case described here, the explosive charge was armed and was placed in the water over 1,000 feet from the ship when the sky was clear. At the time of firing, the weather was deteriorating and the wind was increasing. In these circumstances, there was no risk involved in detonating the charge; however, it would have been hazardous to attempt to recover the explosive or to ride out the storm with the charge in position.

Similar occurrences have been observed during seismic investigations in the Gulf of Mexico (Reference 4). However, no documentation of these has been found.

Detailed discussions of lightning phenomena are available in the literature, i.e., References 3 and 5. Lightning discharges from thunderstorms to the ground, to natural objects, and to man-made structures have been studied for over 200 years and some understanding has been gained of the mechanisms involved. The lightning strike of the underwater explosion plume, however, was unusual in that there was no thunderstorm in the immediate vicinity. The strike was associated with a cloud which was not exhibiting electrical activity.

In most cases of a lightning strike from a cloud to the ground, a stroke starts at the cloud in the form of a stepped leader. The average velocity of this type of leader is of the order of 5×10^5 feet per second. When the leader reaches the earth, a brighter return stroke travels upward from the ground to the cloud. The average velocity of propagation of a return stroke is about 15×10^7 feet per second. Subsequent discharges may occur from the cloud, each followed by a return stroke. The time interval between successive discharges is usually less than 0.1 second and the total duration of a strike is generally less than 0.5 second (Reference 3).

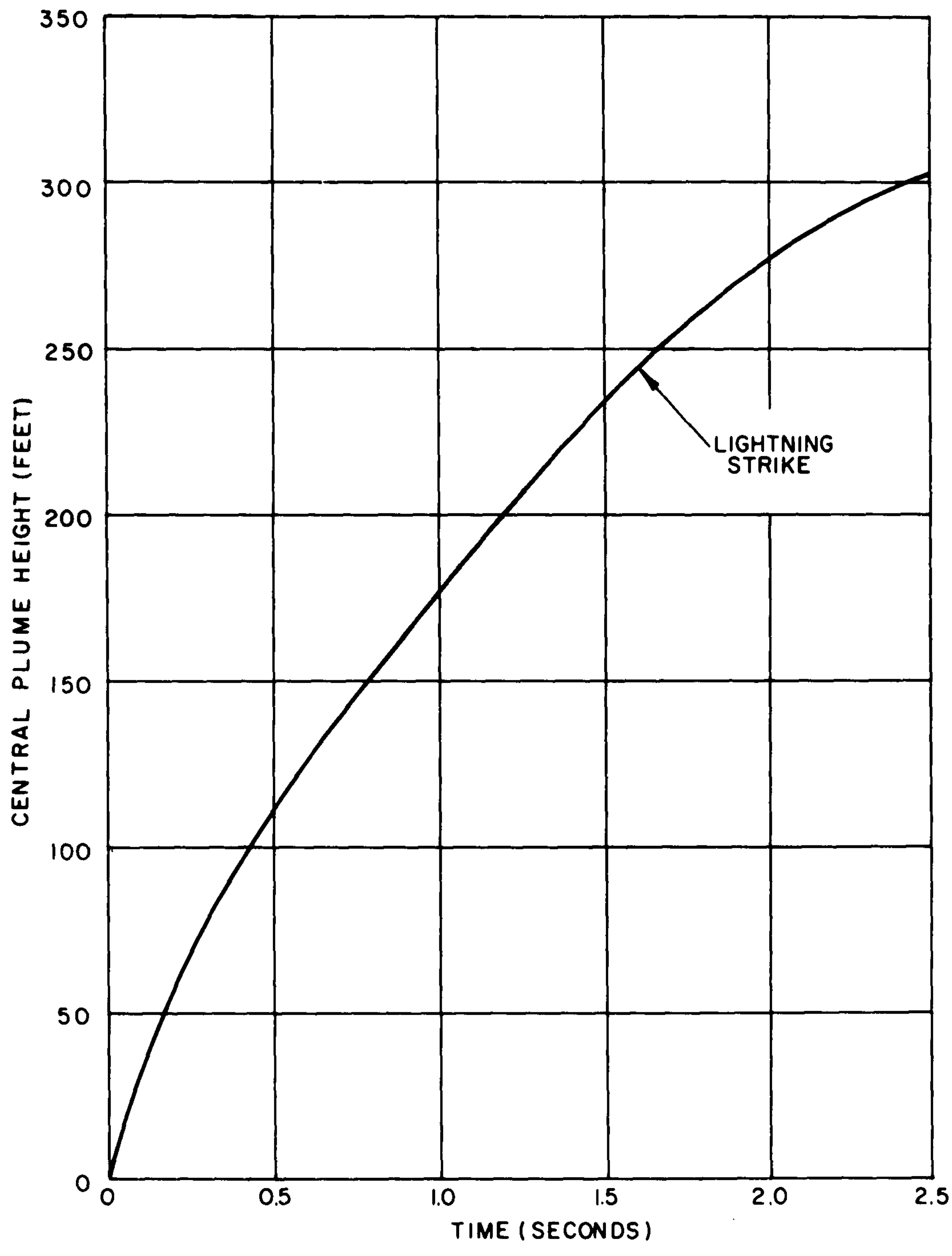


FIG. 3 CENTRAL PLUME HEIGHT VS TIME

In the case of a lightning strike between a cloud and a high building, such as the Empire State Building in New York City, the starting mechanism is quite different (Reference 3). In this case, the stroke usually starts as a stepped leader at the building. Instead of a return stroke, a continuous flow of current is observed; this may be followed by downward leaders from the cloud to the building and upward return strokes to the cloud. The subsequent strokes contain electrical currents of higher amplitude than the current in the initial relatively long stroke.

The photographs of the plume lightning strike were not obtained at a high enough frame rate to resolve the direction of motion of the leaders. In addition, an examination of the film in a microscope failed to reveal any small streamers extending from the main channel which would indicate if the direction was upward or downward. However, the available information indicates that the event was similar to those occurring in the presence of tall buildings. Figure 2 shows an almost constant intensity of illumination during the first stroke, which lasted a total of 0.62 seconds, and the subsequent strokes were shorter and brighter, indicating a stronger current. Thus, the photographic evidence supports the viewpoint that the discharge probably started upward from the plume and drained a widely distributed charge from the cloud at a relatively slow rate.

Investigators of lightning have long been seeking a technique which could be utilized to produce lightning on demand. In most studies of lightning the experimenters select a site where thunderstorms are common, set up their equipment, and then wait for lightning to occur. For example, studies of this type are conducted at Mt. Withington, New Mexico (Reference 6) where electrical activity occurs frequently during the summer and clouds are relatively stationary because of the light winds.

Considerable data has also been collected at locations such as the Empire State Building (Reference 3), which has the characteristics of a giant lightning rod. A lightning rod does not trigger a stroke; however, it is useful for the investigation of lightning because tall objects are more likely to be struck than shorter objects or the ground.

The lightning strike to the rapidly rising plume lends support to the idea that the rapid introduction of a conductor, such as a wire, into the electric field of a storm by the use of a rocket or other device might be a practical method for triggering a lightning stroke. This concept was tested successfully on the laboratory scale by quickly pulling a grounded wire into the electric field near the high voltage electrode of a Van de Graaff generator, thus producing a spark discharge (Reference 4).

A factor which may have contributed to the triggering of the lightning strike by the rising plume is the electrical charge produced by the continuous breakup of water into spray. It is known that charged water drops are produced by such processes as the splashing at the base of a waterfall, the bubbling of air through a liquid, the disintegration of a foam patch on the sea, the formation of whitecaps, and the breakup of liquid jets. It seems almost certain that this process occurs in the rapidly rising plume from an underwater explosion, probably at an extremely rapid rate. Such a highly charged conductor might well be an effective triggering agent. The net sign of the plume charge is not known and can probably not be deduced from existing information because of the complex nature of the charging processes (Reference 7).

If the underwater explosion technique were to be employed as a method for triggering lightning strokes, an area with a high frequency of thunderstorm activity, such as the Gulf Coast of Florida, would be preferable to Chesapeake Bay. In addition, the difficulties involved in deep water operations could be eliminated by placing charges on a beach in relatively shallow water. The greatest vertical plume heights would be obtained at a charge depth given, approximately, by the following equation:

$$d = W^{1/3} \qquad (1)$$

where d = charge depth, feet
W = charge weight, pounds of TNT

For this condition, the maximum plume height is

$$P_{max} = 85\, W^{1/3} \qquad (2)$$

where P_{max} = maximum plume height, feet

For example, if 100-lb TNT charges were to be used, the optimum depth would be 4.6 feet and the plume would reach a height of 390 feet.

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2. Explosions - Electric fields

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A LIGHTNING STRIKE OF AN UNDERWATER EXPLOSION PLUME (U), by George A. Young. 1 Feb. 1962. 22p. Task RE01-ZA732/212 9/-WF008-21-003. UNCLASSIFIED

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1. Lightning - Discharges
2. Explosions - Electric fields

I. Title
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III. Project

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